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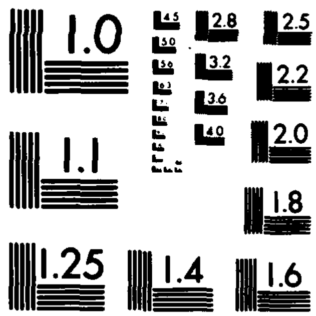

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DSP1, A DIFFRACTOMETER SUBROUTINE PACKAGE FOR PDP-8 COMPUTERS

CHRISTOPHER B. WALKER
METALS RESEARCH DIVISION

November 1983

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ABSTRACT

This report describes a package of subroutines and short programs which, when used in conjunction with the floating point package, FPP1, can control a single crystal X-ray diffractometer in a variety of easily modified experiments.

CONTENTS

INTRODUCTION

The AMMRC diffractometer subroutine package, DSP1, was developed to allow a PDP-8 computer with a 4K memory to control a 4-axis X-ray diffractometer in a variety of step scan and integrated intensity measurements in the AMMRC program of materials research. It is used in conjunction with the AMMRC floating point package, FPP1,[1] ~~described in detail in AMMRC TR 83-47,~~ which it uses for all calculations, input, and output. The general functions of DSP1 include storage and retrieval of scan parameters, conversion of reciprocal space coordinates (for cubic systems) into shaft angle settings, anti-backlash shaft positioning, and fixed time/fixed count X-ray counting (with dead time correction), plus bookkeeping and manipulation to repeat measurements for scans with either one (1-D) or two (2-D) sets of increments. It is composed of 40 subroutines ranging from simple wait loops to complex operations, with the addresses of 31 of these listed on page 0 for easy access, plus a minimal interrupt routine. It also includes a few examples of programs for standard types of measurements. The DSP1 package occupies 978 words of memory, thus, DSP1 and FPP1 together occupy 2079 words, leaving approximately half the 4K memory available for data storage and other programming. As with FPP1, linkages for multiple field operations are left to users with more experience in extended memory systems.

We shall first summarize the particular diffractometer and computer interface characteristics and instructions that are reflected in this package. Next, we describe the function and use of each subroutine, taken roughly in order of increasing complexity. We then consider the examples of standard programs, outlining their use in some detail. Finally, after a few other comments, we include a complete PAL III pass 3 listing of the assembled package.

HARDWARE AND IOT SPECIFICS

The diffractometer axes are driven by Slo-Syn stepping motors which have step intervals of .005° for the 2θ, Ω, and χ rotations and .01° for the ϕ rotation. These intervals are reflected in the conversion constants stored at 4745 ff.

The output pulses from the single channel pulse height analyzer of the X-ray detection electronics are counted in the computer through a data break arrangement that increments memory location 0037. There are no hardware provisions to clear 0037 or to detect its overflow. The time constant for count-rate dead time corrections, DDTAU (3672), has been approximated as 4.0 μ sec; it should be measured accurately for the particular system. The counting circuit and the internal clock are both gated by the same 'Enable' flip-flop.

The internal clock is based on a crystal-controlled clock operating at a frequency of 9.600 kHz. When its gate is enabled, that clock output is scaled by a 5-bit binary scaler to yield 300 pulses per second to set the clock flag. If the Interrupt is on, setting the clock flag causes a program interrupt, and control branches to the interrupt routine to identify the set flag and carry out the operations planned for that situation.

1. **WALKER, C. B.** ***FPP1, A Floating Point Package for PDP-8 Computers.*** **Army Materials and Mechanics Research Center, AMMRC TR 83-47, August 1983.**

The external counter/timer unit is started and stopped by the same 'Enable' flip-flop that controls the internal clock and counting gates. It is reset by a separate signal.

The teletype (TTY) motor can be turned off and on by a program-controlled relay to avoid overheating during long runs.

The program commands, called IOT instructions, that are provided to use this hardware are as follows:

6311 - Skip the next instruction if the clock flag is not set.
6312 - Clear the clock scaler and clock flag, and turn ON the clock/count 'Enable' flip-flop.
6314 - Turn OFF the clock/count 'Enable' flip-flop.
6316 - Clear the clock scaler and clock flag, and turn OFF the clock/count 'Enable' flip-flop.
6321 - Increase the 2θ setting one step.
6322 - Decrease the 2θ setting one step.
6324 - Increase the Ω setting one step.
6331 - Decrease the Ω setting one step.
6332 - Increase the χ setting one step.
6334 - Decrease the χ setting one step.
6341 - Increase the φ setting one step.
6342 - Decrease the φ setting one step.
6344 - Reset the external counter/timer unit.
6351 - Turn OFF the teletype motor.
6352 - Turn ON the teletype motor.
6354 - Unused.

Turning on the computer power establishes the following initial states: the clock/count 'Enable' flip-flop is turned OFF; the clock scaler and clock flag are cleared; the teletype motor is turned ON; and the Interrupt is turned OFF.

SUBROUTINES

The description of each DSP1 subroutine includes its name, a parenthesized Z if its address is listed on page 0, its address, and a brief discussion of its function and usage, as follows:

WAIT (5345) - Do nothing for 2311 machine cycles, ~ .0035 sec. Used, for example, to establish the pulse rate to the stepping motors.
PAWS (5354) - Pause for N wait loops, where -N is in the AC on entry.
TTYOF(Z) (5171) - Turn off TTY motor; pause ~ 1 sec before exit.
TTYON(Z) (5362) - Turn on TTY motor; pause ~1 sec before exit.
SFRMT(Z) (5062) - Set the standard output format: F8.3, with no automatic following carriage return/line feed.
FCMIN (4714) - Set FAC to $\sim 2^{-128}$; used to avoid division problems when FAC = 0.
ARCSIN (4721) - Calculate $\sin^{-1}$ (FAC), and leave the result (limited to the range, $\pm\frac{\pi}{2}$) in FAC. If FAC > 1 on entry, set FAC to $\sim 2^{+565}$ so the angle will be ignored as exceeding diffractometer limits.

TRICR(Z) (5000) - Tricrement (i.e., add three to) locations V1 and V2; used in manipulating a series of sequentially stored 3-word floating point numbers.

DO3A(Z) (5114)
DO3B(Z) (5122) - Do the program between JMS DO3A and JMS DO3B three times, tricrementing V1 and V2 after each pass. V2 must be preset before entry; V1 may be either preset (then AC = 0) or carried in AC on entry to DO3A. These delimit a 3-cycle DO loop for operations on 3 sequentially stored variables, e.g., vector components.

READA(Z) (5011) - Input an angle (in deg) which is converted to motor steps with the multiplier at the address in V2 and stored at the address in V1; V1 and V2 are tricremented before exit.

TYPEA(Z) (5025) - Output the angle (in deg) stored at the address in V1, after conversion from motor steps using the multiplier at the address in V2; V1 and V2 are tricremented before exit.

RSTAS(Z) (4210) - Input (in deg) a set of angles - 2θ, χ, φ - which are converted to motor steps and stored in consecutive (floating point word) locations, with the address of the first either preset in V1 (so AC = 0) or carried in AC on entry.

READV(Z) (5130) - Input vector components (3), which are stored consecutively, with the address of the first (the vector address) either preset in V1 (so AC = 0) or carried in AC on entry.

SHFTV(Z) (5140) - Get the vector (3 components) with the vector address in V2 and store it at the vector address in V1.

TYPEV(Z) (5150) - Output the components of the vector with the vector address in V1.

ADDV(Z) (5160) - Add the vector with the vector address in V1 to the vector with the vector address in V2 and store the resultant vector at the vector address in V1.

MPYV (4671) - Form the scalar product of the vectors with the vector addresses in V1 and V2, and leave the result in FAC.

MPYVH (4707) - Form the scalar product of the vector with the vector address in V1 and the diffraction vector **H** (vector address: 4532), and leave the result in FAC.

TYPEX(Z) (4000) - If the vector address of the diffraction vector **H** is in AC on entry, output the components of **H**; if the address of 2θ is in AC on entry, output (in deg) the set of angles: 2θ, χ, φ. Any unwanted angle output may be suppressed by changing the appropriate "4526" instruction to "4521."

TYCPS(Z) (5073) - Output the corrected count rate, CPS (3700), in counts/sec.

TYCNT(Z) (5102) - Output the measured counts stored in HICNT, LOCNT (3676, 3677) in integer format I8; then reset for standard format.

RCOMI(Z) (4200) - Input an integer <4096 and exit with its complement in AC.

CTLMT(Z) (4173) - Input a preset count limit (in units of 4096), an integer not to exceed 2047. This limit will apply to all the scans in a programmed series of measurements.

TMLMT(Z) (3707) - Input a preset time limit (in sec) which is converted to scaled clock pulses and stored at the address in V1. Each scan in a programmed series has its own preset time limit.

DFLMT(Z) (5036) - Input (in deg) the set of diffractometer angle limits - $2\theta_{upper}$, $2\theta_{lower}$, χ_{upper}, χ_{lower} - which are converted and stored as TTHU (5232), etc.

XTAL(Z) (4400) - First, input the Miller indices specifying the direction in the single crystal of the vector **N** parallel to the φ axis of rotation (**N**||**H** when $\chi = 0$); next, input the Miller indices specifying the direction of the vector **P** perpendicular up from the diffraction plane when $\chi = \varphi = 0$. These are normalized and stored, along with the derived components of the 3rd orthogonal vector, **T** = **P** x **N**. Input, finally, the value of $\lambda/2a_o$, where λ is the X-ray wavelength and a_o is the unit cell edge. This routine, and the routine ANGLE discussed next, are used to calculate the 2θ, χ, and φ settings for a given position of the diffraction vector **H** in reciprocal space. They apply only to crystals with cubic symmetry.

ANGLE(Z) (4600) - Calculate, convert to motor steps, and store the set of angles - 2θ, χ, φ - for a given diffraction vector **H** and the crystal specifics entered with XTAL using the algorithms:

$$2\theta = 2 \sin^{-1}(|H|\lambda/2a_o) \qquad \varphi = - \tan^{-1}(H_t/H_p)$$

$$\chi = \mathrm{sgn}(H_p) \tan^{-1}[(H_t{}^2 + H_p{}^2)^{\frac{1}{2}}/H_n].$$

H and its components along **N**, **T**, and P are all in units of $a_o{}^{-1}$.

LIMIT(Z) (5200) - Test whether 2θ and χ are within the specified diffractometer angle limits. If either angle is outside its limits, exit the subroutine normally; if both are within their limits, exit to the second instruction after the subroutine call.

MOVE (5272) - Change a specified angle by N motor steps, where the integer N is in HORD, LORD (0045, 0046) on entry. If N < 0, a 40-step overrun and runback is added so that the final motion is towards increasing angle, as an anti-backlash provision. The address of the IOT instruction to decrease that angle one step is in LIMIT (5200) on entry. Rotation is at a constant rate, ~280 steps/sec, without initial or final ramping.

RUNOVR (5332) - Add -40 to the integer in HORD, LORD; used in MOVE above.

STEP(Z) (5246) - Move (anti-backlash) the three diffractometer angles from their current settings, stored in TTHO ff, to their new settings, stored in TTH ff. The angles changed are those whose IOT step instructions are the first three pairs of entries in the table beginning at 5370.

CNTADD (3727) - Update the count stored in HICNT, LOCNT by transferring the contents of the data break counter, DBCNTR (0037), to LOCNT and incrementing HICNT if the new LOCNT number is smaller than the previous one (i.e., DBCNTR has overflowed). When updating is done at each clock interrupt, missed overflows should occur only for count rates $\sim 10^6$ counts/sec, and at such rates dead time losses are already prohibitively large.

COUNT(Z) (3600) - Count X-ray pulses (using CNTADD) up to the preset time or preset count limit, whichever is first, and calculate and store in CPS the X-ray count rate corrected for dead time losses. This uses the interrupt routine, changing the response address to select the actions appropriate to the begin, run, and stop phases as needed. This is the only use of the interrupt facility in this package.

CLEAR(Z) (3717) - Clear various flags and registers identified in the PAL III listing. This is a first step in most programs.

BASIC(Z) (4163) - This block routine incorporates the following routines needed at the start of most measurements: clear flags and registers; input diffractometer angle limits; input the current diffractometer angle settings; input the preset count limit; and set the standard output format.

INDTS(Z) (4222) - This block routine handles input and storage of the data defining the various 1-D or 2-D scans in a desired series of measurements. Input, first, the number of scans in the series. For each scan in turn, input its preset time limit, the three initial settings (angles or components of **H**, depending on the type of scan), the increments for each variable in a scan step, and the number of such steps. For 2-D scans, input also the second increments for each variable, and the number of these second steps. A switch address, SWADD (4257), is preset to treat the data as angles or as components of **H**; all the scans in a series must be of that same type. If 2-D scans are involved, for which AC = 7777 on entry, the data for all scans must have the 2-D format; in this case, a real 1-D scan is achieved by having 1 as the second step number. These data are stored sequentially in two series; namely, the floating point numbers in locations 1600 thru 3477 and the integers in 3500 thru 3577 (see STOREZ, ISTORZ, and COUNT). That storage is sufficient for a series of 32 2-D scans or 45 1-D scans.

GTNDS(Z) (4262) - Bring the data defining the next scan to be run in the series from storage to the appropriate active program locations. Retrieves data stored by INDTS.

SCNET(Z) (4321) - This block routine carries out the complete programmed series of step scan measurements. The data defining a scan are retrieved, and for each point on that scan, the diffractometer angles are calculated and positioned, the X-ray intensity is measured for the preset time (or preset count), and the results are typed out. This is repeated for each of the programmed scans. The output at each point consists of the three variables (angles or components of **H**, as per scan type), the measured count, and the count rate (counts/sec) corrected for dead time. In angle scans, any unwanted angle typout may be suppressed by a program change as discussed in TYPEX, but note that this suppression applies to all of the scans in the series.

SCINT(Z) (4020) - This block routine carries out a complete programmed series of integrated intensity scan measurements. These are 2-D angle-type scans similar to those of SCNET, but, for each second increment step, the measured count rate (corrected for dead time) is summed over all points in the set of first increment steps, and the single line of output for that pass consists of its three initial angle settings (unwanted typouts suppressed as discussed above) and its integrated corrected count rate, I. By presetting ANGX (4153) and PPRX (4154) to refer to an angle A given a significant second increment, an average value of A is also calculated at the end of the scan; a final line of output gives, first, a sum of the products, (I-B)*A, over all second increment steps, then a sum of I-B over all such steps, and

finally, from their quotient, the average value of A. B is a preset integrated background cutoff; the quantities (I-B) for any second step are included in the calculations only if (I-B)>0.

STANDARD PROGRAMS

Complete programs of four different types have been included in this package for both their usefulness for standard measurements and calculations and as examples of how to program using DSP1.

Program I, with Start Address (SA) = 0312, calculates the angles, 2θ, χ, and φ, that correspond to a given diffraction vector **H** for a cubic crystal of specified orientation and $\lambda/2a_o$. It is used, for example, to calculate the angles at various checkpoints to verify the accuracy of diffractometer angle settings during a series of measurements. One enters first the crystal specifications: the components of **N** and **P** and the constant, $\lambda/2a_o$ (see XTAL). Then input of any set of components of **H** (in units of a_o^{-1}) gives rise to output of the corresponding values for 2θ, χ, and φ (in deg), in that order, and the program jumps back to await the next vector **H**. As an illustration, we consider a crystal with [111] parallel to the φ axis, $[\bar{2}11]$ up vertical to the diffraction plane when $\chi = \varphi = 0$, and with $\lambda/2a_o = 0.23858$, and we want the angles corresponding to the vector, (H1, H2, H3) = (2.25, 2.25, 1.25). The TTY printout could look as follows:

```
1 1 1   -2 1 1   0.23858↵

2.25  2.25  1.25    109.300   -13.818    60.000
```

where ↵ indicates input of the non-printing character, carriage return.

The three programs involving intensity measurements all begin with the same initialization, JMS I BASICZ, in which one first enters the set of diffractometer angle limits ($2\theta_u$, $2\theta_\ell$, χ_u, χ_ℓ), then the current diffractometer angle settings ($2\theta_o$, χ_o, φ_o), and finally, the preset count limit. The angles are in degrees, and the preset count is in units of 4096 counts. A typical TTY printout of this initialization, with carriage returns to improve appearance, might look as follows:

```
160.  5.  16.  -55.↵

120.  0.  0.↵

100↵
```

Program II carries out step scan measurements with three angles as variables. These may be either 1-D scans (e.g., scans with a given $\Delta 2\theta$), for which SA = 0330, or 2-D scans (e.g., scans with a given $\Delta 2\theta$, repeated with χ incremented by $\Delta\chi$), for which SA = 0323; the different Start Addresses allow registers and switches to be preset without manual intervention. After initialization, INDTS is used to enter the scan data - the number of scans in the series, and for each scan, the preset time, the initial angle settings, the first angle increments, the number of such steps, and for 2-D scans, the second angle increments, and the number of these second steps; preset times are in seconds, and angles are in degrees. The routine SCNET carries out the programmed series of measurements, outputting for each point

the three diffractometer angles (in deg) (see TYPEX for the suppression of unwanted angle typouts), the measured count, and the count rate (counts/sec) corrected for dead time. The program then halts at 0340. The three angles controlled by this program are those whose negative and positive IOT step instructions are stored as pairs in locations 5370 thru 5375, given here as the standard set, 2Δ, χ, and φ. If program control of Ω is needed, its pair of IOT instructions (now in 5376, 5377) must be substituted manually for one of the other pairs (if Ω replaces φ, one must also change the number in 4753 from 0015 to 0016), and one must remember afterwards to reestablish the standard set expected in other programs. As an illustration, a TTY printout of the data input after initialization for a 2θ step scan from 97^{o} to 103^{o} in $.05^{o}$ intervals, with 10-second counts at each point, bracketed by 100-second background counts at the start and finish, could look as follows:

```
3
100.   97.  0  0    0  0  0  1
 10.   97.  0  0  .05  0  0  121
100.  103.  0  0    0  0  0  1
```

The present data storage (see INDTS) will allow a series of up to 15 such background/scan/background sets. A double space separates the output of each separate scan. A single space would separate the output for each second increment step in a 2-D scan.

Program III is similar to program II, except that the variables are the components of **H** (in units of a_o^{-1}) rather than the three angles. One can run a series of 1-D scans (linear scans in reciprocal space), for which SA = 0351, or a series of 2-D scans (points on planar nets), for which SA = 0343. After initialization, one first enters the crystal specifications (see program I above); next, INDTS is used to enter the scan data - the number of scans in the series, and for each scan, the preset time, the initial vector components (H1, H2, H3), the component increments in step 1, the number of such steps, and for 2-D scans, the component increments for step 2, and the number of those second steps. The routine SCNET then carries out the series of measurements, outputting for each point the vector components (H1, H2, H3), the measured count, and the count rate (counts/sec) corrected for dead time. The program then halts at 0362. As an illustration, the TTY printout of the data input after initialization for a 2-D rectangular net scan in the $(1\bar{1}0)$ plane containing the (222) reciprocal lattice point for the crystal specified in program I, with 30-second counts at each point, could look as follows:

```
1 1 1   -2 1 1   0.23858
1
30.  2.05  1.90  1.90   .01  .01  .01  11   -.02  01  .01  11
```

The net intervals here are .01[111] and $.01[\bar{2}11]$.

Program IV carries out integrated intensity scans with three angles as variables. These are 2-D type scans as in program II, but for each second increment step the corrected count rate is summed over all points in the set of first increment steps. This is used, for example, to determine lattice parameters from

single crystal reflections. After initialization, INDTS is used to enter the scan data - the number of scans in the series, and for each scan in turn, the preset time, the initial angle settings, the angle increments for step 1, the number of such steps, the angle increments for step 2, and the number of these second steps. Finally, an estimate of an integrated background rate, B, is entered. The routine SCINT then carries out the series of measurements, outputting for each step 2 in a scan its three initial angle settings (see TYPEX for the suppression of unwanted angle typouts) and its integrated count rate, I, with a final line after each scan giving first a sum of products, (I-B)*A, over all step 2, next a sum of (I-B), over all step 2, and then, from their quotient, an average value for A, where A is a preselected angle given a significant second increment (see SCINT). After all scans are completed the program halts at 0376. The integrated background, B, is a cutoff value [the quantities (I-B) are included in the calculations only if (I-B)>0] that applies to all scans in the series, thus, the actual backgrounds for all the scans in a series should be similar if this is to be useful. The TTY printout of the data input after initialization differs from a 2-D program II printout only by one final entry, B, so an illustration is unnecessary.

DISCUSSION

DSP1 was developed to control a 4-axis X-ray diffractometer in a variety of diffuse-scattering and integrated-intensity measurements on single crystal samples where only three axes are actually under program control at any one time. Control of the usual three axes - 2θ, χ, and φ - was sufficient for most of this work, and the changes to include Ω in the controlled set in place of one of the others could easily be made by hand; consequently, we have not tried to extend the routines further. DSP1 can also control a variety of experiments on an X-ray powder diffractometer (e.g., line profiles), though for such cases one surely can produce a significantly smaller control package of comparable effectiveness by eliminating the several routines and quantities appropriate just to single crystal work.

The stepping of each axis from one position to the next is done at a constant rate, ~280 steps/sec (i.e., 1.4 deg/sec for 2θ, χ, or Ω, and 2.8 deg/sec for φ), with no gradual acceleration at the start or deceleration at the finish (i.e., ramping). Spot checks of angle positions during and after runs over several days in our experiments showed that the Slo-Syn motors were able to respond at that rate without errors. The loading of the various axes here was not large, so if heavy loads (e.g., cryostats) are to be driven, one should recheck this point.

The DSP1 programming is all on a single level, with no attempt to exploit the computer interrupt feature to carry out two tasks "simultaneously," such as calculations and pulse counting. As the package is now arranged, almost all of the time during pulse counting periods is spent idling (jumping in place), waiting for the next clock flag interrupt. That time could be used for other tasks by more sophisticated programming, with a possible increase in the effective dead time as the only anticipated drawback. In our uses, the non-counting time has been such a small fraction of the total run time that there has been no incentive to try that approach, but in experiments involving shorter measurements or longer calculations, it could offer a significant improvement.

The present package has reserved locations 1600 thru 3577 for storage of scan data. This leaves more than 700 locations in a 4K memory that are not used or reserved by DSP1 and FPP1 and that are available for further data storage or for program additions and improvements. The user is urged to regard this package as a flexible tool, to which additions and modifications should be made freely to fit changing needs and as a rewarding educational exercise.

```
          /DIFFRACTOMETER SUBROUTINE PACKAGE  -  AMMRC DSP1
          /
          /               12 JULY 1983
          /
          /THIS IS A COLLECTION OF SUBROUTINES TO SIMPLIFY
          /WRITING PROGRAMS TO CONTROL A THREE-AXIS X-RAY
          /DIFFRACTOMETER.  IT USES THE AMMRC FPP1 FLOATING
          /POINT PACKAGE.  THE INTERRUPT ROUTINE INCLUDED IS
          /JUST A BARE MINIMUM.  A FEW EXAMPLES OF PROGRAMS
          /FOR STANDARD OPERATIONS ARE INCLUDED.
          /
          /
          *0001
0001 3032           DCA ACSAVE
0002 5433           JMP I INIPT
0003 6312 CUT2,     6312              /CLEAR CLOCK FLAG
0004 1032 CUT1,     TAD ACSAVE
0005 6001           ION
0006 5400           JMP I 0
0007 7000           7000
          *0015
0015 0000 AUT1,     0
          *0032
0032 0000 ACSAVE,   0
0033 0200 INIPT,    INIRT
0034 0003 CLOCK,    CUT2
0035 0000 V1,       0
0036 0000 V2,       0
0037 0000 DBCNTR,   0                 /DATA BREAK COUNTER
0040 0000 EX1,      0                 /AMMRC FPP1 USES 0007, 0015,
0041 0000 AC1H,     0                 /AND 0040 THROUGH 0064.
0042 0000 AC1L,     0
0043 0000 OVER1,    0
0044 0000 EXP,      0
0045 0000 HORD,     0
0046 0000 LORD,     0
0047 0000 OVER2,    0
0050 0000 QUOL,     0
0051 0000 LOC1,     0
0052 0000 LOC2,     0
0053 0000 LOC3,     0
0054 0003 NDEC,     0003
0055 0010 NDIG,     0010
0056 0027 NBRX,     0027
0057 0000 NBRHI,    0
0060 0000 NBRLO,    0
0061 7777 SWIT1,    7777
0062 7370 READ,     7370
0063 7172 TYPE,     7172
0064 5724 CRLF,     5724
0065 4532 HIZ,      HI                /KEY WORD, STORAGE ADDRESSES
0066 3500 ISTORZ,   3500
0067 1600 STOREZ,   1600
```

```
0070  5370  TTHNPZ,   TTHNP
0071  4756  TTHZ,     TTH
0072  4767  TTH0Z,    TTH0
0073  5160  ADDVZ,    ADDV                 /SUBROUTINE ADDRESSES
0074  4600  ANGLEZ,   ANGLE
0075  4163  BASICZ,   BASIC
0076  3717  CLEARZ,   CLEAR
0077  3600  COUNTZ,   COUNT
0100  4173  CILMIZ,   CILMI
0101  5036  DFLMIZ,   DFLMI
0102  5114  DO3AZ,    DO3A
0103  5122  DO3BZ,    DO3B
0104  4262  GINDSZ,   GINDS
0105  4222  INDISZ,   INDIS
0106  5200  LIMITZ,   LIMIT
0107  4200  RCOMIZ,   RCOMI
0110  5011  READAZ,   READA
0111  5130  READVZ,   READV
0112  4210  RSTASZ,   RSTAS
0113  4020  SCINIZ,   SCINI
0114  4321  SCNEIZ,   SCNEI
0115  5062  SFRMIZ,   SFRMI
0116  5140  SHFTVZ,   SHFTV
0117  5246  STEPZ,    STEP
0120  3707  TMLMIZ,   TMLMI
0121  5000  TRICKZ,   TRICK
0122  5171  TTYOFZ,   TTYOF
0123  5362  TTYONZ,   TTYON
0124  5102  TYCNTZ,   TYCNT
0125  5073  TYCPSZ,   TYCPS
0126  5025  TYPEAZ,   TYPEA
0127  5150  TYPEVZ,   TYPEV
0130  4000  TYPEXZ,   TYPEX
0131  4400  XTALZ,    XTAL

            *0200
0200  6311  INTRT,    6311                 /SKIP IF NO CLOCK FLAG
0201  5434            JMP I CLOCK
0202  6031            KSF                  /SKIP IF READER FLAG SET
0203  7410            SKP
0204  4462            JMS I READ
0205  6042            TCF
0206  5004            JMP OUTT

            /
            /PROGRAM EXAMPLES
            /
            *0312
            /CALCULATE 3-AXIS ANGLES
0312  4476            JMS I CLEARZ
0313  4531            JMS I XTALZ
0314  1065            TAD HIZ
0315  4511            JMS I READVZ
0316  4474  SCNTTH,   JMS I ANGLEZ
0317  1071            TAD TTHZ
```

```
0320  4530              JMS I TYPEXZ
0321  4464              JMS I CRLF
0322  5314              JMP SCNTTH-2
                /
                /SCAN BY ANGLE INCREMENTS
0323  4475              JMS I BASICZ      /2-D SCAN START
0324  1112              TAD RSTASZ
0325  3741              DCA I SWADD1
0326  7040              CMA
0327  5333              JMP .+4
0330  4475              JMS I BASICZ      /1-D SCAN START
0331  1112              TAD RSTASZ
0332  3741              DCA I SWADD1
0333  4505              JMS I INDTSZ
0334  1007              TAD 0007
0335  3742              DCA I SWADD2
0336  1071              TAD TTHZ
0337  4514              JMS I SCNETZ
0340  7402              HLT
0341  4257  SWADD1,     SWADD
0342  4334  SWADD2,     SCNT1
                /
                /SCAN BY RECIPROCAL SPACE VECTOR INCREMENTS
0343  4475              JMS I BASICZ      /2-D SCAN START
0344  4531              JMS I XTALZ
0345  1111              TAD READVZ
0346  3741              DCA I SWADD1
0347  7040              CMA
0350  5355              JMP .+5
0351  4475              JMS I BASICZ      /1-D SCAN START
0352  4531              JMS I XTALZ
0353  1111              TAD READVZ
0354  3741              DCA I SWADD1
0355  4505              JMS I INDTSZ
0356  1316              TAD SCNTTH
0357  3742              DCA I SWADD2
0360  1065              TAD HTZ
0361  4514              JMS I SCNETZ
0362  7402              HLT
                /
                /INTEGRATING SCAN
0363  4475              JMS I BASICZ
0364  1112              TAD RSTASZ
0365  3741              DCA I SWADD1      / PRESET "TYPEX" TO ELIMINATE
0366  7040              CMA               / USELESS PRINTOUTS
0367  4505              JMS I INDTSZ
0370  4407              JMS I 0007        / PRESET "ANGX" AND "PPRX" TO
0371  0010              0010              / REFER TO SECOND INCREMENT ANGLE
0372  6777              FPUT I BKGND1
0373  0000              FEXT
0374  1071              TAD TTHZ
0375  4513              JMS I SCINTZ
0376  7402              HLT
0377  4474  BKGND1,     BKGND
                /
```

```
                *3600
3600  0000  COUNT,    0
3601  4317            JMS CLEAR
3602  4407            JMS I 0007
3603  5302            FGET LOCLK        /SET REGISTERS FOR PRESET TIME
3604  0012            NEGATE
3605  6300            FPUT CPS
3606  0000            FEXT
3607  1217            TAD CLKC0
3610  3034            DCA CLOCK
3611  2302            ISZ LOCLK
3612  7000            NOP
3613  3037            DCA DBCNTR        /CLEAR DATA BREAK COUNTER
3614  6312  RTN2,     6312              /START CLOCK AND COUNT
3615  6001  RTN1,     ION
3616  5216            JMP .             /IDLING
3617  3620  CLKC0,    CLKCI
3620  4327  CLKCI,    JMS CNTADD
3621  2302            ISZ LOCLK
3622  5231            JMP CNTCK
3623  2301            ISZ HICLK
3624  5231            JMP CNTCK
3625  1230  CLKSW,    TAD CLKC1
3626  3034            DCA CLOCK
3627  5214            JMP RTN2
3630  3636  CLKC1,    CNTSTP
3631  1276  CNTCK,    TAD HICNT
3632  1305            TAD MAXCT
3633  7710            SPA CLA
3634  5214            JMP RTN2
3635  5225            JMP CLKSW
3636  6316  CNTSTP,   6316              /STOP CLOCK AND COUNT
3637  4327            JMS CNTADD
3640  1302            TAD LOCLK
3641  1304            TAD LOTIM
3642  3060            DCA 0060
3643  7004            RAL
3644  1301            TAD HICLK
3645  1303            TAD HITIM
3646  3057            DCA 0057
3647  4407            JMS I 0007
3650  0013            FLOAT
3651  6300            FPUT CPS
3652  5275            FGET XCNT
3653  7000            FNOR
3654  3267            FMPY CLKRAT
3655  4300            FDIV CPS
3656  6300            FPUT CPS          /COUNT RATE (C.P.S.)
3657  3272            FMPY DDTAU
3660  0012            NEGATE
3661  1706            FADD I ENO
3662  0014            INVERT
3663  3300            FMPY CPS
3664  6300            FPUT CPS          /COUNT RATE CORRECTED FOR DEADTIME
3665  0000            FEXT
3666  5600            JMP I COUNT
```

```
3667  0011  CLKRAT,   0011              /300 CLOCK SIGNALS PER SECOND
3670  2260            2260
3671  0000            0000
3672  7757  DDTAU,    7757              /SYSTEM DEAD TIME, PRESET HERE
3673  2061            2061              /AS 4.00 MICROSECONDS
3674  5736            5736
3675  0027  XCNT,     0027
3676  0000  HICNT,    0
3677  0000  LOCNT,    0
3700  0000  CPS,      0
3701  0000  HICLK,    0
3702  0000  LOCLK,    0
3703  0000  HITIM,    0
3704  0000  LOTIM,    0
3705  0000  MAXCT,    0
3706  5666  ENO,      5666
3707  0000  TMLMT,    0                 /INPUT PRESET TIME (SEC.)
3710  4407            JMS I 0007
3711  0010            0010
3712  3267            FMPY CLKRAT
3713  0015            FIX
3714  6435            FPUT I VT
3715  0000            FEXT
3716  5707            JMP I TMLMT
3717  0000  CLEAR,    0                 /CLEARS THE FOLLOWING:
3720  6032            KCC               /   AC AND KEYBOARD FLAG
3721  6042            TCF               /   TELEPRINTER FLAG
3722  6344            6344              /   EXTERNAL EQUIPMENT
3723  3276            DCA HICNT         /   COUNT HI-REGISTER
3724  3277            DCA LOCNT         /   COUNT LO-REGISTER
3725  6316            6316              /   CLOCK FLAG AND SCALER
3726  5717            JMP I CLEAR
3727  0000  CNTADD,   0                 /UPDATE COUNT REGISTERS
3730  1037            TAD DBCNTR
3731  3307            DCA TMLMT
3732  1277            TAD LOCNT
3733  7450            SNA               /WAS LAST READING ZERO?
3734  5343            JMP .+7           /YES, OVERFLOW NOT POSSIBLE
3735  7141            CLL CMA IAC
3736  1307            TAD TMLMT
3737  7430            SZL               /NEW READING > OLD?
3740  5343            JMP .+3           /YES, NO OVERFLOW
3741  2276            ISZ HICNT         /NO, CORRECT FOR OVERFLOW
3742  7000            NOP
3743  7300            CLA CLL
3744  1307            TAD TMLMT
3745  3277            DCA LOCNT         /STORE NEW READING
3746  5727            JMP I CNTADD
```

```
                *4000
4000  0000  TYPEX,    0                /OUTPUT DIFFRACTOMETER SETTINGS
4001  3035            DCA V1
4002  1035            TAD V1           /ENTER WITH HI IN AC TO OUTPUT
4003  7041            CMA IAC          /RECIPROCAL SPACE COORDINATES
4004  1065            TAD HIZ
4005  7640            SZA CLA
4006  5211            JMP .+3
4007  4527            JMS I TYPEVZ
4010  5600            JMP I TYPEX
4011  1217            TAD PPRIT2       /ENTER WITH TTH IN AC TO OUTPUT
4012  3036            DCA V2           /ANGLES TWO-THETA, CHI, PHI
4013  4526            JMS I TYPEAZ     /"JMS I TRICRZ" = 4521  IN ANY
4014  4526            JMS I TYPEAZ     /OF THESE TO ELIMINATE THAT
4015  4526            JMS I TYPEAZ     /PRINTOUT (TTH, CHI, PHI)
4016  5600            JMP I TYPEX
4017  4745  PPRIT2,   PPRIT
4020  0000  SCINT,    0                /INTEGRATING SCAN ROUTINE
4021  4504            JMS I GINDSZ
4022  4464            JMS I CRLF       /SUMS COUNT AS ANGLES STEP BY
4023  3337            DCA SUM3         /INCR. #1, OUTPUTS INTEGRAL
4024  3340            DCA SUM3+1
4025  3341            DCA SUM3+2       /REPEATS WITH INITIAL ANGLES
4026  3342            DCA SUM2         /SHIFTED BY INCR. #2
4027  3343            DCA SUM2+1
4030  3344            DCA SUM2+2
4031  4515  SCIN2,    JMS I SFRMTZ     /FINAL OUTPUT: SUM OF PRODUCTS
4032  1071            TAD TTHZ         /(INTEGRAL ABOVE BACKGND TIMES
4033  4200            JMS TYPEX        /VALUE OF ANGLE GIVEN INCR. #2);
4034  1055            TAD NDIG         /SUM OF INTEGRAL ABOVE BACKGND;
4035  1335            TAD EXTRA        /RATIO = AVERAGE VALUE FOR ANGLE
4036  3055            DCA NDIG         /GIVEN INCR. #2
4037  4522            JMS I TTYOFZ
4040  3345            DCA SUM
4041  3346            DCA SUM+1
4042  3347            DCA SUM+2
4043  1750            TAD I NINCR2
4044  3200            DCA TYPEX
4045  4517  SCIN1,    JMS I STEPZ
4046  4477            JMS I COUNTZ
4047  4407            JMS I 0007
4050  1345            FADD SUM
4051  6345            FPUT SUM
4052  6751            FPUT I CPS2
4053  0000            FEXT
4054  1352            TAD DIRTU
4055  3036            DCA V2
4056  1071            TAD TTHZ
4057  4473            JMS I ADDVZ
4060  2200            ISZ TYPEX
4061  5245            JMP SCIN1
4062  4407            JMS I 0007
4063  5751            FGET I CPS2
4064  2736            FSUB I BKGND2
4065  6345            FPUT SUM
4066  0000            FEXT
```

```
4067  1045            TAD HORD
4070  7710            SPA CLA
4071  5304            JMP SCIN0
4072  4407            JMS I 0007
4073  1342            FADD SUM2
4074  6342            FPUT SUM2
4075  5753            FGET I ANGX
4076  4754            FDIV I PPRX
4077  4755            FDIV I RDPDG1
4100  3345            FMPY SUM
4101  1337            FADD SUM3
4102  6337            FPUT SUM3
4103  0000            FEXT
4104  4523  SCIN0,    JMS I TYONZ
4105  4525            JMS I TYCPSZ
4106  4464            JMS I CRLF
4107  1356            TAD D2H1U
4110  3036            DCA V2
4111  1357            TAD H01U
4112  4473            JMS I ADDVZ
4113  1357            TAD H01U
4114  3036            DCA V2
4115  1071            TAD I1HZ
4116  4516            JMS I SHFTVZ
4117  2760            ISZ I N2NCR2
4120  5231            JMP SCIN2
4121  4407            JMS I 0007
4122  5337            FGET SUM3
4123  4342            FDIV SUM2
4124  6345            FPUT SUM
4125  0000            FEXT
4126  1361            TAD SUM3P
4127  4527            JMS I TYPEVZ
4130  4515            JMS I SFRMTZ
4131  4464            JMS I CRLF
4132  2762            ISZ I RNCNT1
4133  5221            JMP SCIN1+1
4134  5620            JMP I SCIN1
4135  0010  EXTRA,    0010
4136  4474  BKGND2,   BKGND
4137  0000  SUM3,     0
4140  0000            0
4141  0000            0
4142  0000  SUM2,     0
4143  0000            0
4144  0000            0
4145  0000  SUM,      0
4146  0000            0
4147  0000            0
4150  4554  N1NCR2,   N1NCR
4151  3700  CPS2,     CPS
4152  4543  D1H1U,    D1H1
4153  4767  ANGX,     TTH0               /(CHI0), (PHI0)
4154  4745  PPRX,     PPR11              /(PPRCH), (PPRPH)
4155  5022  RDPDG1,   RDPDEG
```

```
4156  4566  D2H1U,   D2H1
4157  4555  H01U,    H01
4160  4577  N2NCR2,  N2NCR
4161  4137  SUM3P,   SUM3
4162  4261  RNCNT1,  RNCNT
4163  0000  BASIC,   0                /BASIC STARTUP ROUTINE
4164  4476           JMS I CLEARZ
4165  4501           JMS I DFLMTZ     /TTHU, TTHL, CHIU, CHIL (DEG.)
4166  1072           TAD TTH0Z
4167  4512           JMS I RSTASZ     /TTH0, CHI0, PHI0 (DEG.)
4170  4373           JMS CTLMT        /PRESET COUNT
4171  4515           JMS I SFRMTZ
4172  5763           JMP I BASIC
4173  0000  CTLMT,   0                /INPUT PRESET COUNT (UNIT: 4096)
4174  4507           JMS I RCOMIZ     /NUMBER SHOULD BE < 2048
4175  3777           DCA I MAXCT1
4176  5773           JMP I CTLMT
4177  3705  MAXCT1,  MAXCT

            *4200
4200  0000  RCOMI,   0                /READ, COMPLEMENT INTEGER (<4096)
4201  4407           JMS I 0007       /EXIT WITH COMPLEMENT IN AC
4202  0010           0010
4203  0015           FIX
4204  0000           FEXT
4205  1046           TAD LORD
4206  7041           CMA IAC
4207  5600           JMP I RCOMI
4210  0000  RSTAS,   0                /READ, STORE ANGLE SET
4211  7440           SZA
4212  3035           DCA V1
4213  1221           TAD PPRT13
4214  3036           DCA V2
4215  4510           JMS I READAZ
4216  4510           JMS I READAZ
4217  4510           JMS I READAZ
4220  5610           JMP I RSTAS
4221  4745  PPRT13,  PPRT1
4222  0000  INDTS,   0                /INPUT DATA SETS
4223  3260           DCA DIMSW        /AC = 7777 FOR 2-D CASES
4224  4200           JMS RCOMI        /NO. OF DATA SETS
4225  3262           DCA GTNDS
4226  1262           TAD GTNDS
4227  3261           DCA RNCNT
4230  1067           TAD STOREZ
4231  3035           DCA V1
4232  1066           TAD ISTORZ
4233  3321           DCA SCNET
4234  4520  INDT1,   JMS I TMLMTZ     /PRESET TIME (SEC.)
4235  4521           JMS I TRICRZ
4236  4657           JMS I SWADD      /STARTING VALUES
4237  4657  INDT2,   JMS I SWADD      /INCREMENTS
4240  4200           JMS RCOMI        /NO. OF STEPS
4241  3721           DCA I SCNET
4242  2321           ISZ SCNET
4243  2260           ISZ DIMSW        /SECOND INCREMENTS?
```

```
4244  5250            JMP .+4          /NO
4245  7344            CLA CLL CMA RAL  /YES
4246  3260            DCA DIMSW
4247  5237            JMP INDI2
4250  2262            ISZ GINDS        /MORE DATA SETS?
4251  5234            JMP INDI1        /YES
4252  1066            TAD ISTORZ       /NO, FINISHED
4253  3200            DCA RCOMI        /SET POINTERS
4254  1067            TAD STOREZ
4255  3210            DCA RSTAS
4256  5622            JMP I INDIS
4257  0000  SWADD,    0                /SWITCH ADDRESS
4260  0000  DIMSW,    0
4261  0000  RNCNT,    0
4262  0000  GINDS,    0                /GET NEXT DATA SET
4263  7440            SZA
4264  3257            DCA SWADD
4265  1210            TAD RSTAS
4266  3036            DCA V2
4267  4407            JMS I 0007
4270  5436            FGET I V2
4271  6720            FPUT I LOCLK1
4272  0000            FEXT
4273  4521            JMS I TRICRZ
4274  1257            TAD SWADD
4275  4516            JMS I SHFTVZ
4276  1374            TAD DIHIT
4277  4516  GIND1,    JMS I SHFTVZ
4300  1600            TAD I RCOMI
4301  3435            DCA I V1
4302  2200            ISZ RCOMI
4303  2035            ISZ V1
4304  1036            TAD V2
4305  3210            DCA RSTAS
4306  2260            ISZ DIMSW        /SECOND INCREMENTS?
4307  5662            JMP I GINDS      /NO
4310  1257            TAD SWADD        /YES
4311  3036            DCA V2
4312  4516            JMS I SHFTVZ
4313  7344            CLA CLL CMA RAL
4314  3260            DCA DIMSW
4315  1210            TAD RSTAS
4316  3036            DCA V2
4317  5277            JMP GIND1
4320  3702  LOCLK1,   LOCLK
4321  0000  SCNET,    0                /SCAN ON 1-D OR 2-D NET
4322  4262            JMS GINDS
4323  4464            JMS I CRLF
4324  5331            JMP .+5
4325  1373  SCNT2,    TAD H011
4326  3036            DCA V2
4327  1257            TAD SWADD
4330  4516            JMS I SHFTVZ
4331  4464            JMS I CRLF
4332  1775            TAD I NINCR1
4333  3222            DCA INDIS
```

```
4334   4474   SCNT1,    JMS I ANGLEZ       /"NOP" FOR ANGLE SET
4335   4506             JMS I LIMITZ
4336   5356             JMP SCNT0
4337   4517             JMS I STEPZ
4340   4522             JMS I TTYOFZ
4341   4477             JMS I COUNTZ
4342   4523             JMS I TTYONZ
4343   1257             TAD SWADD
4344   4530             JMS I TYPEXZ
4345   4524             JMS I TYCNTZ
4346   4525             JMS I TYCPSZ
4347   4464             JMS I CRLF
4350   1374             TAD D1HIT
4351   3036             DCA V2
4352   1257             TAD SWADD
4353   4473             JMS I ADDVZ
4354   2222             ISZ INDTS
4355   5334             JMP SCNT1
4356   2260   SCNT0,    ISZ DIMSW
4357   5370             JMP GONX1
4360   7040             CMA
4361   3260             DCA DIMSW
4362   1376             TAD D2HIT
4363   3036             DCA V2
4364   1373             TAD H01T
4365   4473             JMS I ADDVZ
4366   2777             ISZ I N2NCRI
4367   5325             JMP SCNT2
4370   2261   GONX1,    ISZ RNCNT          /ALL DATA SETS DONE?
4371   5322             JMP SCNET+1        /NO
4372   5721             JMP I SCNET        /YES
4373   4555   H01T,     H01
4374   4543   D1HIT,    D1H1
4375   4554   N1NCRI,   N1NCR
4376   4566   D2HIT,    D2H1
4377   4577   N2NCRI,   N2NCR

              *4400
4400   0000   XTAL,     0                  /INPUT CRYSTAL DATA
4401   1272             TAD N11
4402   3321             DCA T1
4403   7144             CLL CMA RAL
4404   3322             DCA T1+1
4405   1321             TAD T1             /INPUT AND NORMALIZE N1, N2, N3
4406   5212             JMP .+4
4407   0000   LO2A,     0                  /LAMBDA/2A STORAGE, FOR EASY
4410   0000             0                  /ADDRESS
4411   0000             0
4412   4511             JMS I READVZ
4413   1321             TAD T1
4414   3035             DCA V1
4415   1035             TAD V1
4416   3036             DCA V2
4417   4673             JMS I MPYV1
4420   4407             JMS I 0007
```

```
4421  0002            SQROOT
4422  6324            FPUT I2
4423  0000            FEXT
4424  1321            TAD T1
4425  4502            JMS I DO3AZ
4426  4407            JMS I 0007
4427  5435            FGET I V1
4430  4324            FDIV I2
4431  6435            FPUT I V1
4432  0000            FEXT
4433  4503            JMS I DO3BZ
4434  1035            TAD V1          /INPUT AND NORMALIZE P1, P2, P3
4435  3321            DCA T1
4436  2322            ISZ T1+1
4437  5205            JMP XTAL+5
4440  4407            JMS I 0007      /CALCULATE T1, I2, I3
4441  5302            FGET N2
4442  3316            FMPY P3
4443  6321            FPUT I1
4444  5305            FGET N3
4445  3313            FMPY P2
4446  2321            FSUB I1
4447  6321            FPUT I1
4450  5305            FGET N3
4451  3310            FMPY P1
4452  6324            FPUT I2
4453  5277            FGET N1
4454  3316            FMPY P3
4455  2324            FSUB I2
4456  6324            FPUT I2
4457  5277            FGET N1
4460  3313            FMPY P2
4461  6327            FPUT I3
4462  5302            FGET N2
4463  3310            FMPY P1
4464  2327            FSUB I3
4465  6327            FPUT I3
4466  0010            0010            /INPUT LAMBDA/2A
4467  6207            FPUT LO2A
4470  0000            FEXT
4471  5600            JMP I XTAL
4472  4477  NIT,      N1
4473  4671  MPYV1,    MPYV
4474  0000  BKGND,    0
4475  0000            0
4476  0000            0
4477  0000  N1,       0
4500  0000            0
4501  0000            0
4502  0000  N2,       0
4503  0000            0
4504  0000            0
4505  0000  N3,       0
4506  0000            0
4507  0000            0
```

```
4510  0000  P1,     0
4511  0000          0
4512  0000          0
4513  0000  P2,     0
4514  0000          0
4515  0000          0
4516  0000  P3,     0
4517  0000          0
4520  0000          0
4521  0000  T1,     0
4522  0000          0
4523  0000          0
4524  0000  T2,     0
4525  0000          0
4526  0000          0
4527  0000  T3,     0
4530  0000          0
4531  0000          0
4532  0000  H1,     0
4533  0000          0
4534  0000          0
4535  0000  H2,     0
4536  0000          0
4537  0000          0
4540  0000  H3,     0
4541  0000          0
4542  0000          0
4543  0000  D1H1,   0
4544  0000          0
4545  0000          0
4546  0000  D1H2,   0
4547  0000          0
4550  0000          0
4551  0000  D1H3,   0
4552  0000          0
4553  0000          0
4554  0000  N1NCK,  0
4555  0000  H01,    0
4556  0000          0
4557  0000          0
4560  0000  H02,    0
4561  0000          0
4562  0000          0
4563  0000  H03,    0
4564  0000          0
4565  0000          0
4566  0000  D2H1,   0
4567  0000          0
4570  0000          0
4571  0000  D2H2,   0
4572  0000          0
4573  0000          0
4574  0000  D2H3,   0
4575  0000          0
4576  0000          0
4577  0000  N2NCK,  0
```

```
                  *4600
4600   0000   ANGLE,     0                  /CALCULATE SHAFT ANGLES FOR
4601   1264              TAD NIP            /A GIVEN VECTOR H
4602   3035              DCA V1
4603   4307              JMS MPYVH
4604   4665              JMS I AMNI7
4605   4314              JMS FCMIN
4606   4407              JMS I 0007
4607   6361              FPUT CHI
4610   0000              FEXT
4611   4307              JMS MPYVH
4612   4665              JMS I AMNI7
4613   4314              JMS FCMIN
4614   4407              JMS I 0007
4615   6356              FPUT TTH
4616   0001              SQUARE
4617   6364              FPUT PHI
4620   0000              FEXT
4621   4307              JMS MPYVH
4622   4407              JMS I 0007
4623   6266              FPUT Y
4624   0001              SQUARE
4625   1364              FADD PHI
4626   0002              SQROOT
4627   4361              FDIV CHI
4630   0005              ARCTAN
4631   3350              FMPY PPRCH
4632   0000              FEXT
4633   1357              TAD TTH+1
4634   7710              SPA CLA
4635   4663              JMS I ACNEG7
4636   4407              JMS I 0007
4637   6361              FPUT CHI           /CHI (MOTOR STEPS)
4640   5266              FGET Y
4641   4356              FDIV TTH
4642   0005              ARCTAN
4643   3353              FMPY PPRPH
4644   0012              NEGATE
4645   6364              FPUT PHI           /PHI (MOTOR STEPS)
4646   0000              FEXT
4647   4307              JMS MPYVH
4650   4407   LO2A1,     JMS I 0007
4651   0002              SQROOT
4652   3650              FMPY I LO2A1
4653   0000              FEXT
4654   4321              JMS ARCSIN
4655   2044              ISZ EXP
4656   7001   SMALL,     7001               /AN ADDRESS, NO EFFECT ON CALC
4657   4407              JMS I 0007
4660   3345              FMPY PPRTT
4661   6356              FPUT TTH           /TWO-THETA (MOTOR STEPS)
4662   0000              FEXT
4663   5600   ACNEG7,    JMP I ANGLE
4664   4477   NIP,       N1
4665   6655   AMNI7,     6655
```

```
4666  0000  Y,       0
4667  0000           0
4670  0000           0
4671  0000  MPYV,    0                  /MAKES SCALAR PRODUCT OF VECTORS
4672  3044           DCA EXP            /WITH ADDRESSES IN V1 AND V2
4673  3045           DCA HORD
4674  3046           DCA LORD
4675  4502           JMS I DO3AZ
4676  4407           JMS I 0007
4677  6706           FPUT I X1
4700  5435           FGET I V1
4701  3436           FMPY I V2
4702  1706           FADD I X1
4703  0000           FEXT
4704  4503           JMS I DO3BZ
4705  5671           JMP I MPYV
4706  5734  X1,      5734
4707  0000  MPYVH,   0
4710  1065  LARGE,   TAD H1Z
4711  3036           DCA V2
4712  4271           JMS MPYV
4713  5707           JMP I MPYVH
4714  0000  FCMIN,   0                  /SET FAC = 2**-128
4715  4407           JMS I 0007
4716  5656           FGET I SMALL
4717  0000           FEXT
4720  5714           JMP I FCMIN
4721  0000  ARCSIN,  0                  /ARCSINE
4722  1044           TAD EXP
4723  7740           SMA SZA CLA        /IF FAC > 1, SET FAC = 2**565
4724  5340           JMP UNREAL
4725  4407           JMS I 0007
4726  6266           FPUT Y
4727  3266           FMPY Y
4730  0012           NEGATE
4731  1744           FADD I EIN
4732  0002           SQROOT
4733  0014           INVERT
4734  3266           FMPY Y
4735  0005           ARCTAN
4736  0000           FEXT
4737  5721           JMP I ARCSIN
4740  4407  UNREAL,  JMS I 0007
4741  5310           FGET LARGE
4742  0000           FEXT
4743  5721           JMP I ARCSIN
4744  5666  EIN,     5666
4745  0016  PPRTI,   0016               /(200*180/PI)
4746  2630           2630
4747  3117           3117
4750  0016  PPRCH,   0016               /(200*180/PI)
4751  2630           2630
4752  3117           3117
4753  0015  PPRPH,   0015               /(100*180/PI)
4754  2630           2630
4755  3117           3117
```

```
4756  0000  ITH,     0
4757  0000           0
4760  0000           0
4761  0000  CHI,     0
4762  0000           0
4763  0000           0
4764  0000  PHI,     0
4765  0000           0
4766  0000           0
4767  0000  ITH0,    0
4770  0000           0
4771  0000           0
4772  0000  CHI0,    0
4773  0000           0
4774  0000           0
4775  0000  PHI0,    0
4776  0000           0
4777  0000           0

            *5000
5000  0000  TRICR,   0                  /TRICREMENTS V1 AND V2
5001  1035           TAD V1
5002  1210           TAD C3
5003  3035           DCA V1
5004  1036           TAD V2
5005  1210           TAD C3
5006  3036           DCA V2
5007  5600           JMP I TRICR
5010  0003  C3,      0003
5011  0000  READA,   0                  /INPUT ANGLE (DEG.), CONVERT TO
5012  4407           JMS I 0007         /MOTOR STEPS, AND STORE
5013  0010           0010
5014  3436           FMPY I V2
5015  3222           FMPY RDPDEG
5016  6435           FPUT I V1
5017  0000           FEXT
5020  4200           JMS TRICR
5021  5611           JMP I READA
5022  7773  RDPDEG,  7773               /(PI/180)
5023  2167           2167
5024  6432           6432
5025  0000  TYPEA,   0                  /CONVERT ANGLE FROM MOTOR STEPS TO
5026  4407           JMS I 0007         /DEGREES AND OUTPUT IT.
5027  5435           FGET I V1
5030  4436           FDIV I V2
5031  4222           FDIV RDPDEG
5032  0011           0011
5033  0000           FEXT
5034  4200           JMS TRICR
5035  5625           JMP I TYPEA
5036  0000  DFLMT,   0                  /INPUT DIFFRACTOMETER LIMITS:
5037  1254           TAD PPRIT1         /ITHU, ITHL, CHIU, CHIL (DEG.)
5040  3036           DCA V2
5041  1255           TAD ITHU1
5042  3035           DCA V1
5043  4211           JMS READA
```

```
5044  1254              TAD PPRIT1
5045  3036              DCA V2
5046  4211              JMS READA
5047  4211              JMS READA
5050  1256              TAD PPRCH1
5051  3036              DCA V2
5052  4211              JMS READA
5053  5636              JMP I DFLMT
5054  4745    PPRIT1,   PPRIT
5055  5232    TTHU1,    TTHU
5056  4750    PPRCH1,   PPRCH
5057  0000              0                   /UNUSED
5060  0000              0
5061  0000              0
5062  0000    SFRMT,    0                   /SET STANDARD OUTPUT FORMAT:
5063  1271              TAD ND              /F8.3, NO FOLLOWING CR-LF
5064  3054              DCA 0054
5065  1272              TAD NT
5066  3055              DCA 0055
5067  3061              DCA 0061
5070  5662              JMP I SFRMT
5071  0003    ND,       0003
5072  0010    NT,       0010
5073  0000    TYCPS,    0                   /OUTPUT COUNT RATE
5074  4407              JMS I 0007
5075  5701              FGET I CPS1
5076  0011              0011
5077  0000              FEXT
5100  5673              JMP I TYCPS
5101  3700    CPS1,     CPS
5102  0000    TYCNT,    0                   /OUTPUT COUNT (FORMAT I8)
5103  3054              DCA 0054
5104  4407              JMS I 0007
5105  5713              FGET I XCNT1
5106  7000              FNOR
5107  0011              0011
5110  0000              FEXT
5111  4262              JMS SFRMT           /RESET TO STANDARD FORMAT
5112  5702              JMP I TYCNT
5113  3675    XCNT1,    XCNT
5114  0000    DO3A,     0                   /THREE CYCLE DO-LOOP
5115  7440              SZA
5116  3035              DCA V1
5117  7146              CLL CMA RTL
5120  3327              DCA DOCNT
5121  5714              JMP I DO3A
5122  0000    DO3B,     0
5123  4200              JMS TRICK
5124  2327              ISZ DOCNT
5125  5714              JMP I DO3A
5126  5722              JMP I DO3B
5127  0000    DOCNT,    0
5130  0000    READV,    0                   /INPUT VECTOR (3 COMPONENTS)
5131  4314              JMS DO3A
5132  4407              JMS I 0007
5133  0010              0010
```

```
5134  6435            FPUT I V1
5135  0000            FEXT
5136  4322            JMS DO3B
5137  5733            JMP I READV
5140  0000  SHFTV,    0                   /SHIFT VECTOR
5141  4314            JMS DO3A
5142  4407            JMS I 0007
5143  5436            FGET I V2
5144  6435            FPUT I V1
5145  0000            FEXT
5146  4322            JMS DO3B
5147  5740            JMP I SHFTV
5150  0000  TYPEV,    0                   /OUTPUT VECTOR
5151  4314            JMS DO3A
5152  4407            JMS I 0007
5153  5435            FGET I V1
5154  0011            0011
5155  0000            FEXT
5156  4322            JMS DO3B
5157  5750            JMP I TYPEV
5160  0000  ADDV,     0                   /ADD TWO VECTORS
5161  4314            JMS DO3A
5162  4407            JMS I 0007
5163  5435            FGET I V1
5164  1436            FADD I V2
5165  6435            FPUT I V1
5166  0000            FEXT
5167  4322            JMS DO3B
5170  5760            JMP I ADDV
5171  0000  TTYOF,    0                   /TURN TTY OFF
5172  6351            6351
5173  1376            TAD TMLAG2
5174  4777            JMS I PAWS1         /WAIT ONE SECOND
5175  5771            JMP I TTYOF
5176  7400  TMLAG2,   7400
5177  5354  PAWS1,    PAWS

            *5200
5200  0000  LIMIT,    0                   /TEST IF TTH AND CHI ARE WITHIN
5201  4407            JMS I 0007          /SPECIFIED LIMITS.  IF NO, EXIT
5202  5232            FGET TTHU           /NORMALLY.  IF YES, EXIT TO
5203  2471            FSUB I TTHZ         /SECOND INSTRUCTION.
5204  6630            FPUT I TMP3
5205  5471            FGET I TTHZ
5206  2235            FSUB TTHL
5207  3630            FMPY I TMP3
5210  0000            FEXT
5211  1045            TAD HORD
5212  7710            SPA CLA
5213  5600            JMP I LIMIT
5214  4407            JMS I 0007
5215  5240            FGET CHIU
5216  2631            FSUB I CHIL
5217  6630            FPUT I TMP3
5220  5631            FGET I CHIL
```

```
5221  2243           FSUB CHIL
5222  3630           FMPY I TMP3
5223  0000           FEXT
5224  1045           TAD HORD
5225  7700           SMA CLA
5226  2200           ISZ LIMIT
5227  5600  ACNEG6,  JMP I LIMIT
5230  5745  TMP3,    5745
5231  4761  CHI1,    CHI
5232  0000  TTHU,    0
5233  0000           0
5234  0000           0
5235  0000  TTHL,    0
5236  0000           0
5237  0000           0
5240  0000  CHIU,    0
5241  0000           0
5242  0000           0
5243  0000  CHIL,    0
5244  0000           0
5245  0000           0
5246  0000  STEP,    0                /MOVES (ANTIBACKLASH) THREE AXES
5247  1070           TAD TTHNPZ       /TO NEW POSITIONS
5250  3200           DCA LIMIT
5251  1072           TAD TTH0Z
5252  3036           DCA V2
5253  1071           TAD TTHZ
5254  4502           JMS I DO3AZ
5255  4407           JMS I 0007
5256  5435           FGET I V1
5257  2436           FSUB I V2
5260  0015           FIX
5261  6630           FPUT I TMP3
5262  7000           FNOR
5263  1436           FADD I V2
5264  6436           FPUT I V2
5265  5630           FGET I TMP3
5266  0000           FEXT
5267  4272           JMS MOVE
5270  4503           JMS I DO3BZ
5271  5646           JMP I STEP
5272  0000  MOVE,    0                /AB-MOVE AXIS (HORD,LORD) STEPS
5273  4731           JMS I AMN16      /IS FAC = 0?
5274  5326           JMP NOGO         /YES, NO MOTION
5275  1045           TAD HORD
5276  7700           SMA CLA
5277  5303           JMP .+4
5300  4332           JMS RUNOVR       /FAC < 0; OVERRUN AND RUNBACK
5301  7040           CMA
5302  5305           JMP .+3
5303  2200           ISZ LIMIT        /FAC > 0
5304  4627           JMS I ACNEG6
5305  3044           DCA EXP          /AB RUNBACK SWITCH
5306  1600           TAD I LIMIT
5307  3312           DCA PULSE
```

```
5310  7410            SKP
5311  4345            JMS WAIT
5312  0000  PULSE,    0                   /MOTOR PULSE
5313  2046            ISZ LORD
5314  5311            JMP PULSE-1
5315  2045            ISZ HORD
5316  5311            JMP PULSE-1
5317  2200            ISZ LIMIT
5320  2044            ISZ EXP             /RUNBACK NEEDED?
5321  5672            JMP I MOVE          /NO, DONE
5322  1276            TAD MOVE+4
5323  4354            JMS PAWS            /WAIT A FRACTION OF A SECOND
5324  4332            JMS RUNOVR
5325  5306            JMP PULSE-4
5326  2200  NOGO,     ISZ LIMIT
5327  2200            ISZ LIMIT
5330  5672            JMP I MOVE
5331  6655  AMNT6,    6655
5332  0000  RUNOVR,   0                   /ADDS -40 TO HORD,LORD
5333  7300            CLA CLL
5334  1344            TAD M40
5335  1046            TAD LORD
5336  3046            DCA LORD
5337  7420            SNL
5340  7040            CMA
5341  1045            TAD HORD
5342  3045            DCA HORD
5343  5732            JMP I RUNOVR
5344  7730  M40,      7730
5345  0000  WAIT,     0                   /WAIT 2311 CYCLES = .0035 SEC.
5346  1353            TAD NWAIT
5347  3047            DCA OVER2
5350  2047            ISZ OVER2
5351  5350            JMP .-1
5352  5745            JMP I WAIT
5353  6400  NWAIT,    6400
5354  0000  PAWS,     0                   /PAUSE N WAIT LOOPS, WHERE -N IN AC
5355  3332            DCA RUNOVR          /ON ENTRY
5356  4345            JMS WAIT
5357  2332            ISZ RUNOVR
5360  5356            JMP .-2
5361  5754            JMP I PAWS
5362  0000  TTYON,    0                   /TURN TTY ON
5363  6352            6352
5364  1367            TAD TMLAG
5365  4354            JMS PAWS            /WAIT ONE SECOND
5366  5762            JMP I TTYON
5367  7400  TMLAG,    7400
5370  6322  TTHNP,    6322                /TTH NEG. MOTOR PULSE
5371  6321            6321                /TTH POS.   "      "
5372  6334  CHINP,    6334                /CHI NEG.   "      "
5373  6332            6332                /CHI POS.   "      "
5374  6342  PHINP,    6342                /PHI NEG.   "      "
5375  6341            6341                /PHI POS.   "      "
5376  6331  OMGNP,    6331                /OMG NEG.   "      "
5377  6324            6324                /OMG POS.   "      "
```

ACNEG6	5227
ACNEG7	4663
ACSAVE	0032
ACIH	0041
ACIL	0042
ADDV	5160
ADDVZ	0073
AMNT6	5331
AMNT7	4665
ANGLE	4600
ANGLEZ	0074
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AJ11	0015
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BASICZ	0075
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C3	5010
DBCNTR	0037
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DFLMTZ	0101
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NBRLO	0060
NBRX	0056
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N1	4477
N1NCR	4554
N1NCR1	4375
N1NCR2	4150
N1P	4664
N1T	4472
N2	4502
N2NCR	4577
N2NCR1	4377
N2NCR2	4160
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PPRPH	4753
PPRTT	4745
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PPRTT2	4017
PPRTT3	4221
PPRX	4154
PULSE	5312
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SCIN2	4031
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SCNT0	4356
SCNT1	4334
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SCNT2	4325
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SFRMTZ	0115
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SHFTVZ	0116
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STOREZ	0067
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SUM3P	4161
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SWADD2	0342
SWIT1	0061
TMLAG	5367
TMLAG2	5176
TMLMT	3707
TMLMTZ	0120
TMP3	5230
TRICR	5000
TRICRZ	0121
TTH	4756
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TTHNP	5370
TTHNPZ	0070
TTHU	5232
TTHU1	5055
TTHZ	0071
TTH0	4767
TTH0Z	0072
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TTYONZ	0123
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TYCPSZ	0125
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TYPEAZ	0126
TYPEV	5150
TYPEVZ	0127
TYPEX	4000
TYPEXZ	0130
T1	4521
T2	4524
T3	4527
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V2	0036
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XCNT1	5113
XTAL	4400
XTALZ	0131
X1	4706
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